# NASAL, OCULAR, DERMAL AND GENERAL SYMPTOMS AMONG SWEDISH COMMERCIAL AIRCREW

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## ABSTRACT
Symptoms among commercial cabin crew was studied. A standardized questionnaire was mailed in February-March 1997 to all airline crew on SAS (N=1857), and office workers (N=218). Smoking was allowed only on intercontinental flights. The participation rate was 81% in the airline crew, and 77% in the office group.The most common symptoms among airline crew were fatigue (21%), nasal symptoms (15%), ocular symptoms (11%), dry or flushed facial skin (12%), and dermal hand symptoms (12%). Airline crew had more nasal symptoms (OR=3.12), throat symptoms (OR=5.75), and more dermal symptoms from the face (OR=2.03), and hands (OR=3.68), as compared to office workers. Airline crew atopy had an increase of most symptoms (OR=1.5-3.8), but age, gender, or smoking was not associated with symptoms. Airline crew that had been on an intercontinental flight last week had more complaints on fatigue (OR=1.87), and heavy-headedness (OR=1.89), and difficulties concentrating (OR=3.22).

## INDEX TERMS
Cabin air quality, Environmental tobacco smoke (ETS), Indoor air quality, Psychosocial work environment, Sick building syndrome (SBS).

## INTRODUCTION
There is little information available on discomfort and irritative symptoms in relation to the indoor environment in commercial airlines. Worldwide more than 1,000 million people are transported by aircraft annually (Owe 1997). Common complaints are irritative symptoms from eyes, nose, throat, and facial skin, as well as headache and fatigue among office workers (Raynal 1995), hospital workers (Nordström et al. 1999), and school personnel (Smedje et al. 1997). Various factors, such as type of ventilation system, high room temperature, low outdoor air supply flow rate, and low air humidity have been shown to influence the prevalence of SBS-symptoms (Sundell et al. 1993). In addition, this type of symptoms may be related to personal factors, such as female gender (Norbäck et al. 1990; Stenberg et al. 1993), age (Engvall et al. 2000), allergic disorders (Björnsson et al. 1998), bronchial hyper responsiveness (Björnsson et al. 1998), and perceived psychosocial work environment (Stenberg et al. 1993). Earlier questionnaire studies of commercial airline crews (Taskin et al. 1983) have found a high prevalence of eye, nose, and throat symptoms, typically 40-70%. In two of these studies the symptom were suspected to be due to ozone exposure (Tashkin et al. 1983), but nowadays the exposure situation is not comparable since many aircrafts have ozone converters. Another historical exposure in the cabin environment has been environmental tobacco smoke (ETS) (Lindgren et al. 1999; Wieslander et al. 2000), but nowadays smoking is prohibited by most commercial airlines. Finally, the cabin environment

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is densely populated, and has a lower relative air humidity than most other workplaces, typically between 5-25% R.H. (Lindgren et al. 2000; Owe 1997). The main aim was to compare the prevalence of different types of symptoms among commercial airline crew with office workers in the same company. The second aim was to identify personal, psychosocial, and occupational factors among airline crew associated with different types of symptoms.

## METHODS

To evaluate the occurrence of symptoms such as tiredness, headache, eye irritation, nasal irritation and dermal irritation, a self-administered questionnaire was mailed in February-March 1997 to all Stockholm airline crew on duty in SAS, and office workers from the same company. About 10% are working on intercontinental flights between Scandinavia and America or Asia, with obvious risk for jet-lag (3-8 h time difference). The participation rate was 81% (N=1513) in the airline crew, and 77% (N=168) in the office group. The questionnaire contained questions from a standardized questionnaire (MM 040 NA) developed by the Department of Occupational and Environmental Medicine in Örebro (Andersson et al. 1992). In addition there were some questions added from another questionnaire (Wålinder et al. 1998), as well as some specific questions for airline crew. During the time of the questionnaire study, smoking was allowed on intercontinental flights. Information on age, gender, smoking habits, allergies, and atopy was obtained from the questionnaire. A history of atopy was defined as reporting allergy to tree or grass pollen, furry animals, or a history of eczema in childhood.

During Scandinavian and European flights, the following aircraft were used: Fokker F-28, Mc Donnell Douglas DC-9-21/41/81, and Mc Donnell Douglas MD-80/90 series. All intercontinental flights were operated by Boeing 767 series. In all aircrafts, the fresh air is supplied by the engines in flight, and sterile while passing through heated zones in the engine (approximately 400 °C). Boeing 767 was the only aircraft type equipped with ozone converter. In all aircraft, the cabin air circulation system utilized a pre-filter for larger particles. In addition, Boeing-767-300, and MD 90 are equipped with high efficiency particulate air filter (HEPA). A charcoal filter to remove volatile compounds, was installed only in the Boeing 767-300. All of the aircraft types have a ventilation system that should be able to give 10 cubic feet (cfm) of fresh air per minute and person, even when the cabin is full of passengers. Since they use a 30-50% air recirculation, the ventilation flow is approximately 20 cubic feet (cfm) of mixed air per minute and person, except F28 and DC9, which have no recirculated air.

The influence of different factors on subjective indoor air quality was analyzed by multiple logistic regressions, by Statistical Package for Social Sciences (SPSS). Dependent variables were the different symptoms, independent variables were the personal and occupational factors described in the aims. Two types of statistical models were used. First, all cabin crew were grouped together, and compared with the office reference group of office workers from the same company, adjusting for possible confounding of age, gender, atopy, current smoking, and the four psychosocial variables. In the next step, the statistical analysis was restricted to all aircraft crew, and type of occupation, age, gender, atopy, current smoking, and the four psychosocial variables simultaneously in the models.Odds ratios (OR) with a 95% confidence interval (CI) were calculated. In all statistical analyses, two-tailed tests and five percent level of significance were used.

## RESULTS

Among all participants, 53% were females, 14% were current smokers, and 19% had hay fever, 9% used contact lenses, and mean age was 43y (SD=8). Prevalence of personal factors



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in different occupations is given below (table 1). In the three-month prevalence of weekly symptoms, the most common complaints among airline crew where fatigue (21%), irritated, stuffy or runny nose (15%). Complaints of dermal symptoms from face (12%), itching, burning or irritation of the eyes (11%), and dermal symptoms (12%) were also common. When comparing the airline crew with office workers, the airline crew had more often irritated, stuffy or runny nose, hoarse, dry throat, cough, dry or flushed facial skin, and hands dry, itching, red skin. Among airline crew, 70-90% of all symptoms were previewed as work-related.

**Table 1.** Personal characteristics (%) for different occupational groups onboard (*n=1513*), and office workers (*n=168*).

| *Variable* | *Pilot* | | *Purser* | | *Steward* | | *Air host(ess)* | | *Office Workers* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | *%* | *n* | *%* | *n* | *%* | *n* | *%* | *n* | *%* |
| Female | 29 | 5 | 170 | 86 | 16 | 20 | 595 | 91 | 46 | 27 |
| Current mokers | 47 | 8 | 40 | 21 | 16 | 20 | 105 | 17 | 32 | 19 |
| Hay fever | 92 | 16 | 30 | 15 | 23 | 28 | 128 | 20 | 34 | 20 |
| Atopy | 150 | 26 | 54 | 27 | 31 | 38 | 220 | 34 | 45 | 27 |

Atopy = history of eczema in childhood, allergy to furry animals, and allergy to tree or grass pollen

The main difference between airline crew and office workers was a difference in the perception of work control. In total, 92% of the office workers reported that they could influence their working conditions (often or sometimes). The corresponding figures for work control were 50% for pilots, 48% for purser, 40% for steward, and 29% for air host (ess). Work stress (often or sometimes) was reported by only 42% of the pilots, but was more common among both office workers (94%), purser (91%), steward (88%), and air host (ess) (82%) Further statistical analysis was performed, applying multiple logistic regression analysis, adjusting for possible confounders; age, gender, atopy, current smoking, and psychosocial work conditions. Airline crew had significantly more nasal symptoms (OR=3.12), throat symptoms (OR=5.75), and more dermal symptoms from the face (OR=2.03), and hands (OR=3.68), as compared to office workers from the same company (table 2).

**Table 2.** Three-month prevalence of weekly complaints of various symptoms among airline crew, and office workers during the last 7 days.

| *Symptoms* | *Airline crew symptoms* | | *Office workers symptoms* | | *Airline crew vs. office workers[a] OR(95%CI)* |
|---|---|---|---|---|---|
| | *n* | *%* | *n* | *%* | |
| Fatigue | 308 | 21 | 37 | 22 | 0.94(0.59-1.50) |
| Feeling heavy-headed | 103 | 7 | 14 | 8 | 0.70(0.34-1.45) |
| Headache | 81 | 6 | 7 | 4 | 1.04(0.42-2.60) |
| Nausea/dizzness | 9 | 0.6 | 1 | 0.6 | 0.79(0.06-10.0) |
| Difficulties concentrating | 19 | 1 | 5 | 3 | 0.49(0.13-1.84) |
| Itching, burning or irritiation of the eyes | 159 | 11 | 13 | 8 | 1.08(0.55-2.13) |
| Irritated, stuffy or runny nose | 217 | 15 | 9 | 6 | 3.12(1.48-6.59)** |
| Hoarse, dry throat | 116 | 8 | 2 | 1 | 5.75(1.35-24.5)* |
| Cough | 59 | 4 | 0 | 0 | not applicable |
| Dry or flushed facial skin | 172 | 12 | 12 | 7 | 2.03(1.01-4.08)* |
| Scaling/itching scalp or ears | 123 | 8 | 11 | 7 | 1.92(0.92-4.00) |
| Hands dry, itching, red skin | 169 | 12 | 6 | 4 | 3.68(1.50-9.05)** |

* p<0.05; ** p<0.01; ***p<0.001 [a]Calculated by multiple logistic regression analysis, including age, gender, atopy, current smoking, 4 psychosocial variables, and type of work in the regression model

In the next step, the logistic regression analysis was restricted to all cabin crew members, controlling for both occupation, age, gender, atopy, current smoking, work satisfaction, work



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stress, influence on working conditions, and social support in the models. No differences between males and females were observed, and no effect was seen for age. Airline crew with a history of atopy (pollen allergy, allergy to furry animals, or childhood eczema) had an increase of most symptoms (OR=1.5-3.8). The prevalence of ocular symptoms was similar in contact lens wearer (13%), as compared to airline crew not wearing contact lenses (11%). Stress due to excess of work was significant associated with fatigue, feeling heavy-headed, difficulties concentrating, headache, and facial dermal symptoms.

When comparing complaints on symptoms between different occupations in airline crew, the level of symptoms among air host (ess) was used as a reference values. The same logistic regression model was applied, adjusting for age, gender, atopy, smoking, and psychosocial work conditions. No major differences were found except for less reporting of ocular and nasal symptoms, and less dermal symptoms from the hand in pilots.

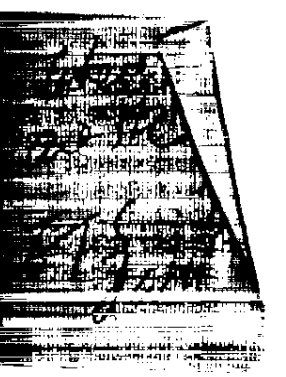
The most frequently reported symptoms among those who had worked on intercontinental flights latest week, where fatigue (33%), and irritated, stuffy or runny nose (16%) (table 3). In the logistic regression analysis, airline crew that had been on an intercontinental flight last week, reported significantly more fatigue, heavy-headedness, and difficulties concentrating (table 3).

**Table 3.** Three-month prevalence of weekly complaints of various symptoms among airline crew, and adjusted odds ratios (OR)[a] with 95 % confidence interval (95% CI) for relationships between symptoms, and work on intercontinental flights during the last 7 days (*n=1513*).

| *Symptoms* | *Work on intercontinental flights (n=270)* | | *Work on european or domestic flights (n=1243)* | | *Work on intercontinental flights OR(95%CI)* |
|---|---|---|---|---|---|
| | *n* | *%* | *n* | *%* | |
| Fatigue | 89 | 33 | 219 | 18 | 1.70(1.42-2.03)*** |
| Feeling heavy-headed | 32 | 12 | 71 | 6 | 1.75(1.33-2.29)** |
| Headache | 14 | 5 | 67 | 5 | 1.22(0.86-1.74) |
| Nausea/dizzness | 3 | 1 | 6 | 0.5 | 1.82(0.60-5.55) |
| Difficulties concentrating | 8 | 3 | 11 | 0.9 | 2.91(1.39-6.13)** |
| Itching, burning or irritiation of the eyes | 33 | 12 | 126 | 10 | 1.06(0.82-1.37) |
| Irritated, stuffy or runny nose | 43 | 16 | 174 | 14 | 1.11(0.90-1.38) |
| Hoarse, dry throat | 27 | 10 | 89 | 7 | 1.24(0.95-1.62) |
| Cough | 15 | 6 | 44 | 4 | 1.22(0.84-1.79) |
| Dry or flushed facial skin | 41 | 15 | 131 | 11 | 1.24(0.96-1.56) |
| Scaling/itching scalp or ears | 30 | 11 | 93 | 8 | 1.13(0.87-1.47) |
| Hands dry, itching, red skin | 29 | 11 | 140 | 11 | 1.26(0.78-1.26) |

* P<0.05; **p<0.01; *** p<0.001

[a]Calculated by multiple logistic regression analysis, including age, gender, atopy, current smoking, 4 psychosocial variables, type of occupation onboard, and work on intercontinental flights.



## DISCUSSION

The study was performed on intercontinental smoke-flights, by the same flight company (SAS) . The increase of dermal symptoms in airline crew could be due to the low relative air humidity in the cabin. (Wieslander et al. 2000; Lindgren et al. 2001). The most important factors associated with symptoms were found to be atopy, stress due to an excess of work, and work on an intercontinental flight.

The study was designed to include all types of airline crew belonging to the crew base in Stockholm, as well as two arbitrary selected units of office workers in Stockholm from the



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same company. The office workers were working outside the airport, in buildings without any known indoor environmental problems or reports on complaints. The response rates was reasonably high both in cabin crew and office workers (82% and 77%, respectively). Information on both present symptoms, and psychosocial work environment, was gathered by the same questionnaire.

Three-month prevalence of weekly complaints of symptoms was common among airline crew, particularly on irritated or stuffy or runny nose, hoarse or dry throat, dry or flushed facial skin hands dry or itching or red skin. A history of atopy was the main predictor of symptoms, while gender, and smoking habits were not associated with symptoms. We found an association between symptoms and the psychosocial work environment, particularly lack of work control.

Pilots had less ocular and nasal symptoms, and less dermal symptoms from the hands, as compared to cabin crew, even when controlling for differences in personal and psychosocial factors. This could be explained by different work tasks, or differences in the cabin air quality. Both pilots and cabin attendants are exposed to dry air, but hygienic demands can be different, with more frequent hand washing in cabin crew. The cabin air quality can be expected to be better on flight deck as compared to the cabin, since pilots are not exposed to pollutants related to passenger's activity, or emissions from materials or activities in the cabin. Moreover, flight deck may have higher personal air flow rate (Lindgren et al. 2001). Finally, we found an increase of general symptoms, such as fatigue and difficulties concentrations, among those with recent work on intercontinental flights where smoking was allowed. This could be related to long working days or jet-lag on long-range flights, but could also partly be due to environmental tobacco smoke (ETS). In a recent study, it was found that ban on smoking, without any change of work schedules or flight times, reduced the prevalence of fatigue on intercontinental flights between Scandinavia and Tokyo (Wieslander et al. 2000). A significant exposure to nicotine in cabin crew, measured as cotinine in urine, has been demonstrated during intercontinental flights where smoking was allowed.

## CONCLUSION AND IMPLICATION

In conclusion, mucosal and dermal symptoms were more common among airline crew than office workers, and many of the airline crew perceived the symptoms as being work-related. We could identify occupational and personal factors associated with symptoms. Important factors were atopic disposition, work stress due to excess of work, and work on intercontinental flights. In the view of the worldwide increase of civil aviation, the working conditions for airline crew needs further attention.

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# MEASUREMENTS OF INDOOR AIR QUALITY ON COMMERCIAL TRANSPORT AIRCRAFT

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## ABSTRACT

Exposures to cabin environmental contaminants were measured on 36 commercial transport aircraft. The objectives were to characterize levels of contaminants and evaluate the relationship between flight factors such as aircraft size, occupancy, ventilation, and flight length, and environmental parameters. Monitoring was conducted at two coach locations for the duration of the flight for VOCs, nitrogen oxides, CO, $CO_2$, $O_3$, temperature, relative humidity, total particulates, and barometric pressure. Five-minute average concentration ranges were: $CO_2$ 515-4902 ppm; $O_3$ <0.05-0.24 ppm; CO <0.2-2.9 ppm; nitrogen oxides <0.05-2.0 ppm; and total particulates <0.028-0.197 mg/m$^3$. Gate-to-gate average concentrations of VOCs were: toluene <3-130 ppb, limonene <3-12 ppb, and ethanol <0.8-2.4 ppb. Carbon dioxide exposures were highest on shorter and high-occupancy flights, aircraft with greater recirculated-to-fresh-air ratio, and narrow-bodied aircraft. In general contaminant levels were low compared to standards. Carbon dioxide levels indicated lower ventilation rates per occupant than most other indoor environments.

## INDEX TERMS

Cabin air quality, Aircraft, Ventilation, Carbon dioxide, Relative humidity

## INTRODUCTION

Much scientific and public interest has focused on cabin air quality in aircraft, which is the workplace of approximately 198,000 flight personnel in the US (Air Transport Association, 2000). Cabin air contaminants may include carbon dioxide, products of combustion such as carbon monoxide, nitrogen oxides, particulates and aldehydes, organic hydrocarbons from engine oil, fuel, hydraulic fluids, de-icing agents, cleaning products, allergens and infectious agents such as viruses and bacteria.

Engine compressor bleed air is pre-conditioned, sent to the air conditioning packs, and delivered to the cabin through a manifold that permits mixing with recirculated cabin air. Outside air is not filtered but the recirculation system incorporates air filtration; types and efficiency of filters vary by aircraft. Recirculation maintains air supply rate and minimizes use of more costly bleed air. While outside supply air at aircraft altitudes is generally very clean, it may become contaminated with engine oil, fuel, and hydraulic fluids aloft. During ground operations hydrocarbon vapors from refueling and other outdoor pollutants may enter the ventilation system (van Netten and Leung, 2000). Ozone may enter the cabin when an aircraft flies through the ozone layer. Although aircraft are equipped with catalytic converters to destroy ozone in bleed air, catalyst age may degrade efficacy.

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In general the outside fresh air ventilation rates in commercial transport aircraft have decreased over the last thirty years to as little as 6.3 $ft^3$/min per person (Hocking, 2000). Commercial aircraft are not required by the Federal Aviation Administration to meet performance criteria with respect to provision of either outside or recirculated air. Federal regulations require design specifications to provide at least 0.55 lb/min per occupant of fresh air which is approximately 10 $ft^3$/min per occupant at 8000 ft pressure (Federal Air Regulation, 1996). These are average ventilation rates per person over all occupied compartments.

Previous measurement studies of cabin air quality on commercial aircraft have been reviewed recently (Nagda, Rector, Zhidong *et al.*, 2001). Most studies have addressed specific aircraft models or parameters such as environmental tobacco smoke and data on aircraft contaminants are few. The objectives for this study were to characterize cabin environmental quality parameters and to the extent possible evaluate the relationship between aircraft type and environmental parameters. This work is part of an exposure assessment for NIOSH health studies of flight crew. Reported here are levels and variability of cabin environmental quality measures including ozone, carbon dioxide, carbon monoxide, nitrogen oxides, volatile organic hydrocarbons, particulates, temperature, relative humidity, pressure, and on smoking-permitted flights environmental tobacco smoke, and the relationship between carbon dioxide and aircraft type.

## METHODS

The study design included 36 commercial transport flight segments on eleven different aircraft. Flight segments were selected to obtain a range of flight durations and latitudes. Flight duration is relevant for pollutants such as carbon dioxide which build up during longer flights and was stratified into three categories: short (<2 hr), medium (2-8 hr), and long (>8 hr). About half of the flights were polar flights (some portion of the flight greater than 50 degrees latitude). Atmospheric ozone levels are higher at high latitudes where the ozone layer can penetrate down to aircraft altitudes. Six smoking-permitted flight segments were included. The cabin environment measurement parameters, sampling and analysis methods, and direct-reading data logging (DRDLI) instruments are summarized in Table 1.

**Table 1.** Environmental parameters monitored and sampling and analysis methods

| Parameter | Sample type | Detection/analysis meth |
|---|---|---|
| $O_3$, CO, nitrogen oxides | DRDLI, passive sampling | electrochemical |
| $CO_2$ | DRDLI, active sampling | non-dispersive infrared |
| VOCs semiquantitative | integrative, thermal desorption tube | GC/MS[1] (NMAM 2549 |
| Aldehydes | integrative, coated porous polymer | GC/FID/MS (NMAM 2 |
| Ethanol | integrative, charcoal | GC FID (NMAM 1400) |
| aliphatic hydrocarbons | integrative, charcoal | GC FID (NMAM 1500) |
| aromatic hydrocarbons | integrative, charcoal | GC FID (NMAM 1501) |
| inhalable particulates | integrative, 25 mm 5 µm PVC | gravimetric |
| total particulates | integrative, 37 mm 5 µm PVC | gravimetric (NMAM 500) |
| respirable particulates | integrative, 37 mm 5 µm PVC | gravimetric (NMAM 600) |
| Nicotine | integrative, porous polymer | gravimetric (NMAM 2551) |

[1]NMAM = NIOSH Manual of Analytical Methods (NIOSH, 1998)
[2]GC = gas chromatography, FID = flame ionization detector, MS = mass spectrometry



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Environmental tobacco smoke and respirable particulates were collected on smoking-permitted flights only. In addition to the contaminants, temperature, relative humidity, and barometric pressure were continuously monitored. Monitoring was performed in the coach compartment in two sampling locations in coach, forward and rear. Sampling probes were clipped on the aisle seat backs above the breathing zone. Sampling was performed continuously from (at minimum) gate departure to gate arrival or "gate-to-gate". Additional samples were collected in other locations for nicotine (smoking flights only). Flight crew provided ventilation air pack usage, airflow schedule settings and passenger counts. For the DRDLI the sampling interval was 5 minutes. Field blanks for analytes sampled on integrative media were collected on each flight segment. Direct-reading data logging instruments (DRDLI) were calibrated before and after each field campaign using span gases (CO and $NO_x$) and chemical methods ($O_3$). Pressure correction factors were applied to air sample measurements.

## RESULTS

The gate-to-gate times for the flight segments ranged from 42 to 863 minutes, with approximately equal allocation to short, medium, and long duration categories. Passenger occupancy ranged from 34-100% of capacity in coach.

### Gases

Carbon monoxide full-flight average levels were generally less than 1 ppm, with 5-minute averages occasionally ranging as high as 9.4 ppm. No differences between front and rear coach location levels or trends by aircraft type were identifiable. Nitrogen oxides averaged 0.57 ppm (sd 0.56 ppm); no significant relationship between concentrations and aircraft type or route or between front and rear coach locations was found. Ozone gate-to-gate average levels ranged from < 0.05 to 0.24 ppm, with the highest five-minute average during a flight averaging 0.17 ppm (n=22). All aircraft were equipped with catalytic ozone converters to reduce in-cabin concentrations. No discernible trend by altitude or by polar/non-polar route was observed. None of the gate-to-gate average ozone levels exceeded the 0.25 ppm Federal Air Regulation (1996) applicable to flights over 32,000 ft.

SD ?

No table

Passenger

### VOCs and aldehydes

The predominant VOC was ethanol, followed by toluene and limonene. Toluene levels ranged from <3 to 130 ppb, limonene from <3-12 ppb, and ethanol from <0.8-2.4 ppm. Levels (ppb) of hexane (<0.004), ethyl acetate (<0.02), formaldehyde (<0.07)and acrolein (<0.2) were detectable but too low to be quantified. Using the semi-quantitative thermal desorption tube method (NIOSH, 1998) trace levels of propylene glycol monomethyl ether acetate , siloxane, tributylphosphate, perchlorethylene, butyl cellosolve, methyl pyrollidine, benzene, and 1-methoxy-2-propanol were found.

### Particulates and nicotine

Full-flight average inhalable particulates averaged 0.12 µg/L and ranged from 0.038 to 0.3 µg/L. Total particulates averaged 0.086 µg/L. Concentrations of both total and inhalable particulates were higher in the rear of coach than the front ($p<0.05$). The ratio of inhalable-to-total particulate averaged 1.4, indicating that the majority (71%) of the mass distribution was comprised of particles smaller than 30 µm. The mean concentration of inhalable particulate did not differ for smoking (0.119 µg/L) versus non-smoking flights (0.123 µg/L). The mean concentration of total particulate were somewhat higher on smoking flights (0.11 µg/L) than on non-smoking flights (0.08 µg/L).



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Respirable particulates (RSP) and nicotine were sampled on six smoking-permitted flights in non-smoking areas of the aircraft. Levels of RSP ranged from 19.9 to 153 $\mu g/m^3$. Nicotine levels ranged from 0.38 to 24.1 $\mu g/m^3$. Coach rear levels were substantially higher than coach front levels for both respirable particulates and nicotine, as expected due to proximity of the rear sampling station to the designated smoking rows in the rear of coach.

CO2 Not in the gas category.

**Carbon dioxide**

Carbon dioxide concentrations in coach averaged over both front and rear locations and over the entire flight period ranged from 874-2328 ppm (mean 1387 ppm, sd=351 ppm). The lowest 5-minute TWAs over the duration of the flight averaged 1021 ppm. Some flights never had $CO_2$ concentrations lower than 1556 ppm. The highest gate-to-gate 5-minute TWAs averaged 2216 ppm, with single values at one location ranging as high as 4902 ppm $CO_2$. The 5-minute TWAs were also parsed into three periods (boarding, midflight, and deboarding) by examining each plot of front plus rear coach average concentrations versus time and developing a cutoff point based on the $CO_2$ levels. The mean $CO_2$ concentrations in ppm during these periods were: 1522 (range=784-3284) during boarding, 1317 (range=751-2217) during midflight, and 1150 (range=818-2439) during deboarding. Geometric standard deviations for each of these distributions were so low (<= 1.4) that it was not possible to distinguish between fit to a normal or lognormal distribution using the Shapiro-Wilk test.

The correlation between several flight factors and carbon dioxide levels was evaluated both parametrically (Spearman) and nonparametrically (Pearson). Two surrogates for aircraft size were used: coach capacity (number of seats) as a continuous discrete variable and narrow body single-aisle aircraft versus wide-body double-aisle aircraft as a dichotomous variable. Occupancy in coach expressed as a percentage of capacity, the flight length in minutes, and the number of air changes per hour for the aircraft were also evaluated. The only significantly correlated factor identified was the occupancy, showing $CO_2$ levels were highly dependent on passenger load ($p<0.01$). The analysis of the effect of air changes per hour on carbon dioxide levels was hindered by the fact that ventilation rates available were averages based on volume of the entire aircraft including the cargo, business class and first class compartments and were not specific to the coach compartment where the $CO_2$ levels were measured. Despite lack of statistical significance, several relationships were evident. $CO_2$ levels were higher on aircraft with recirculation (1352 ppm versus 1144 ppm) and slightly higher on smaller aircraft on short flights (1388 ppm vs. 1256 ppm). $CO_2$ levels were not statistically significantly correlated with flight length or surrogates for aircraft size.

**Relative humidity, temperature and pressure**

Relative humidity ranged vary widely, with gate-to-gate averages ranging from 10.1 to 45.6% (mean=19.8%, sd=6.7%, n=36). Front and rear coach levels were not significantly different. The longest flights had the lowest gate-to-gate averages; some had extended periods around 6-8%RH. Over 50% of the flights had RH averages below 20%, generally the lower cutoff for ASHRAE comfort criteria, dependent on temperature (ASHRAE, 1999). Temperatures ranged between 19-29.5°C (5-minute TWA). The lowest pressures attained on each flight ranged from 574-680 mm Hg (1-minute TWA), with duration-of-flight averages from 609-726 mm HG.

NOx measure ⇒ not comparable to WTC data

**DISCUSSION**

Carbon monoxide and nitrogen oxides air concentrations found in this study were largely comparable to values reported in other aircraft studies (Spengler, Burge, Dumyahn, *et al.*, 1997; Pierce WM, Janczewski JN, Roethlisberger B, *et al.*, 1999). Carbon monoxide levels

how comparable?



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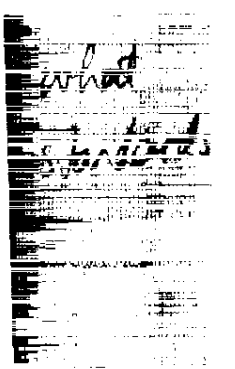
on the B-777 were reported as averaging 0.7 ppm (range 0.8-1.3, n=3) (Spengler *et al.*, 1997). Spengler *et al.* (1997) found nitrogen dioxide levels on the B-777 averaging 36 ppb (range 23-60, n=4); these results are not directly comparable since we measured nitrogen oxides.

Ozone levels in aircraft reported by Nagda, Fortmann, Koontz, *et al.* (1989) averaged 22 ppb on non-smoking flights and 10 ppb on smoking flights. Spengler, Burge, Dumyahn, *et al.* (1997) reported ozone levels on the B-777 to be all below the detection limit which varied from 1.8-9.8 ppb. De Ree, Bagshaw, Simons, *et al.* (2000) found mean levels ranging from 2-28.4 ppb on aircraft with catalytic converters (n=19) and from 43-177 ppb on aircraft without catalytic converters (n=12). They also reported maximums (30 second averaging interval) of 8-159 ppb and 158-383 ppb for aircraft with and without converters, respectively. In this study flight mean levels ranged from <50 to 240 ppb (all on aircraft with converters). The large variation in levels determined between each of these studies is likely a reflection of the difficulty of accurate ozone measurement using portable instrumentation and the difficulty of maintaining calibrations in the field.

But numbers were repo-

VOC levels were low or non-detectable in this study and the profile observed was not atypical for indoor environments. Since these measurements were collected integratively, it was not possible to discern time trends in levels over the course of the flight. However, bioeffluents would likely track the time trends throughout flight of carbon dioxide since both are related to metabolic rate. VOCs associated with meal service, especially ethanol, are likely higher during meal service. VOCs originating from cleaning agents or furnishings would be expected to follow a time course related to ventilation rate, which is lowest during periods when power is needed for thrust, such as take-off and the early ascent phase. Future characterization efforts in the aircraft cabin should use more sensitive VOC methods than used here and include measurement of semi-volatile organic compounds, although the aircraft cabin, with space and power source constraints, poses sampling difficulties not easily overcome. Pesticides, typically pyrethroids, are applied regularly inside aircraft cabins using a method sufficient to leave a residual for six weeks. Yet no pesticide quantitation studies, either of surface contamination or air concentrations, have been performed.



## CONCLUSIONS AND IMPLICATIONS

In general contaminant levels measured here were low compared to standards. Carbon dioxide levels, while not related to any health effects at the levels found here, are indicative of lower ventilation rates per occupant than most other indoor environments. ASHRAE is currently in the process of setting an air quality standard for commercial transport aircraft.

Although symptom and health effect studies have been conducted in non-transportation indoor environments, little symptomatology research has been performed among aircrew (Lee, Poon, Li, *et al.*, 2000). One study comparing aircrew perception of cabin air quality with office workers showed cabin crew complaints about air quality were greater than office workers (Lindgren, Norback, Andersson, *et al.*, 2000), and a survey of passengers concluded that passengers' assessment of cabin air quality was an important determinant of comfort and health-related symptoms (Rankin, Space, and Nagda, 2000). Additional research is needed to investigate the relationship between health effects, symptoms and cabin air quality.

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# CABIN AIR POLLUTANTS AND CLIMATE IN AN AIRCRAFT WITH RECIRCULATED AIR ON INTERCONTINENTAL FLIGHTS

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## ABSTRACT
Measurements of air humidity, temperature, carbon dioxide ($CO_2$), respirable particles, ozone, nitrogen dioxide ($NO_2$), formaldehyde, and volatile organic compounds of possible microbial origin (MVOC) were performed during 26 flights with Boeing 767-300. The mean temperature in cabin was 22.2 °C (range 17.4-26.8 °C), and mean relative air humidity was 6% (range 1-27%). The $CO_2$ during cruises was below 1,000 ppm during 96 % of measured time. Mean concentration of $NO_2$ and ozone $O_3$, were 14.1 $\mu g/m^3$ and 19.2 $\mu g/m^3$, with maximum values of 37 $\mu g/m^3$ and 66 $\mu g/m^3$, respectively. Formaldehyde was below the detection limit (<5 $\mu g/m^3$), in most samples (77%) (Maximum value was 15 $\mu g/m^3$). The mean concentration of respirable particles in the rear part of the cabin was much higher during smoking (mean 49 $\mu g/m^3$: maximum 253 $\mu g/m3$) than non-smoking (mean 3 $\mu g/m^3$) ($p<0.001$). Different MVOC were detected, including 3-methyl-1-butanol, 1-octen-3-ol, at higher levels than in Swedish dwellings.

## INDEX TERMS
Cabin air quality, Carbon dioxide (CO2), Environmental tobacco smoke, Microbial VOC, Relative air humidity

## INTRODUCTION
Aircraft nowadays transports more than 1,000 million people annually (Owe, 1997). Because of increased fuel cost, recirculated is often used in the cabin (Hocking, 2000). In a larger questionnaire study, complaints about cabin environment were found to be more common in aircrew than office workers (Lindgren et al., 2000). In another study on cabin crew, Lee et al (2000) found frequent complaints on the cabin environment, particularly on unpleasant odour and low air humidity. Environmental factors considered in previous studies have included low relative air humidity (5-25%) (Lee et al., 1999; de Ree et al, 2000; Backman et al, 2000), carbon dioxide concentration ($CO_2$) (Haghighat et al., 1999; Lee et al., 1999), particulate pollutants in relation to smoking onboard (e.g. Lee et al., 1999; Dechow et al.; 1997), and chemical pollutants such as ozone ($O_3$) (Reed et al., 1980; Tashkin et al., 1983), formaldehyde, and nitrogen dioxide ($NO_2$) (Pierce et al., 1999; O'Donnell et al., 1991).

why measure?

The main aim was to perform continuous measurements of cabin temperature, air humidity, $CO_2$, and respirable particles in the working areas of an aircraft (Boeing 767) commonly used in intercontinental flights. The second aim was to measure $NO_2$, $O_3$, formaldehyde, and volatile organic compounds of possible microbial origin (MVOC) in cabin air. We also

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studied the influence of selected flight conditions. Initially, all flights had smoking in particular areas. After 1 September 1997, all smoking (both for passengers and personnel) was prohibited on all flights. The ban on smoking enabled us to study the effect of this environmental improvement.

## METHODS

Boeing 767-300, with a total number of 190 seats, was used on all flights. According to information from the producer, the air-conditioning pack gives 2800 cubic feet per minute of fresh outside air, and the same flow of filtered air (50%). This should result in an outdoor air flow rate of approximately 6.6 L/sec per person fresh air in a full aircraft. The fresh air is sterilized by passing it through heated zones in the engine (400 °C), through a catalytic ozone converter. The system utilizes a pre-filter for larger particles, and a high efficiency particulate air filter (HEPA) capturing particles equal or greater than 0.3 μm with 99.99% efficiency, combined with a charcoal filter (The Boeing Company; personal communication).

Measurements were performed in 26 intercontinental flights. They included temperature, relative air humidity, and concentration of respirable particles, $CO_2$, $NO_2$, $O_3$, formaldehyde, and possible microbial origin. Most measurements were restricted to the cruising period, at a flight altitude of 11,000-12,000 meter. During eight of the flights, continuous measurements were performed from gate to gate, to compare cruising and non-cruising conditions. Smoking onboard was allowed until September 1, 1997 (N=19), and was prohibited on all flights after this date (N=7).
Temperature and air humidity were recorded with a SWEMA logger 15 (SWEMA AB, Sweden), sampling 1-min average values. Respirable particles were measured by a direct reading instrument based on light scattering (Sibata P-5H2). An infrared spectrometer (Rieken RI-411A) was used to measure $CO_2$, calibrated at the ground level by standard gases with specified $CO_2$ concentrations. The signal from the particles monitor and the $CO_2$ meter were recorded with the SWEMA logger.

Formaldehyde was measured by sampling on glass fibre filters impregnated with 2,4-dinitrophenylhydrazine (Andersson et al, 1981), (sampling flow 0.2 L/min during four hours). The filters were analysed by liquid chromatography. Nitrogen dioxide was sampled on eight flights with a diffusion sampler (Ferm, 1998a). Ozone was measured on 13 flights with another diffusion sampler from IVL, Sweden (Ferm, 1998b).

Microbial origin was sampled during 4 h (200ml/min) on synthetic charcoal tubes (Anasorb 747; SKC 226-81). The charcoal tubes were desorbed with 2 ml of methylene chloride. VOC of possible microbial origin (MVOC) were determined by selective ion monitoring (SIM)) gas chromatography mass spectrometry (GCMS) (Wessen and Schoeps, 1995). Microbial growth in the mineral fibre insulation in one aircraft was analysed by the CAMNEA method (Palmgren et al., 1986).

## RESULTS

For all measurements, average temperature was 22.2 °C (range 17.4-26.8), and relative air humidity was low (3-8%) during cruise. The mean $CO_2$ concentration was below the recommended limit of 1,000 ppm. (AFS 1993:5) during 96 % of measured time. There were striking differences in the concentration of respirable particles in the rear part of the cabin, when comparing smoke and non-smoking flights. During smoke flights, the average concentration of respirable particles was 49 $\mu g/m^3$ in AFT galley, 8 $\mu g/m^3$ in forward galley.



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During eight flights, the measuring time with the direct reading instruments were extended to gate-to-gate conditions. Cabin temperature, relative air humidity, and carbon dioxide in AFT galley (rear part) were significantly higher during non-cruise conditions ($p<0.001$) (Table 1).

**Table 1.** Continuous, one minute in-flight measurements in aft and fwd galley, at non-cruising and cruising conditions.

| *Aft galley* | *Non-cruising conditions* N min | M(SD) | max- | *Cruising conditions* N | M(SD) | max-min | *Mean difference* | *2-tailed p-value*[a] |
|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | 355 | 23.2 (1.7) | 18.7-27.1 | 5798 | 21.9 (1.9) | 17.4-26.8 | 1.3 | <0.001 |
| Relative humidity (%) | 355 | 29 (7.4) | 6-47 | 6444 | 7.6(3.7) | 2-27 | 21 | <0.001 |
| Carbon dioxide (ppm)[a] | 296 | 1656 (877) | 694-3686 | 3765 | 734(151) | 415-1488 | 922 | <0.001 |
| *Forward galley* | | | | | | | | |
| Temperature (°C) | 173 | 22.2 (1.5) | 17.8-24.9 | 2556 | 22.8 (0.26) | 17.6-24.7 | 0.6 | <0.001 |
| Relative humidity (%) | 175 | 26.8 (8) | 7.3-39.3 | 2536 | 3.2 (2.5) | 0.9-24.8 | 23.6 | <0.001 |
| Carbon dioxide (ppm) | 105 | 1232 (541) | 417-2490 | 1277 | 637 (183) | 410-1406 | 595 | <0.001 |

[a]Calculated for individual 1-min values, by Students' t-test

Relationships between continuously measured data and flight conditions were investigated. The following dependent variables were evaluated: Flight latitude (polar/non-polar), flight altitude, number of passengers, degree of smoking, and location of measuring sites (forward/AFT galley). When comparing measurements near the pole with other flights, no major differences were found. Mean temperature in AFT galley was 21.7 °C (range 17.4-25.4 °C) near the pole, and 22.1 °C (range 18.8-26.8 °C) on non-polar flights. Mean relative air humidity in AFT galley was 7 % (range 2-27%) near the pole, and 8 % (range 2-27%) during non-polar flight.

The influence of number of passengers, flight altitude, and location in the aircraft (aft/forward) on temperature, relative air humidity and $CO_2$-concentration was evaluated, by keeping the three dependent variables simultaneously in linear multiple regression models. In total, 15 flights were almost filled (more than 160 passengers), while nine flights had fewer passengers (86-158 passengers). Flight altitude ranged from 35 000-38 000 feet. Relative air humidity and $CO_2$ were positively related to the number of passengers ($p<0.001$), but the magnitude of the influence was small.

Relative air humidity was negatively related to flight level ($p<0.001$). Both mean temperature, relative air humidity and $CO_2$ were significantly related to the location in the aircraft, with higher levels in AFT galley (Table 2).

**Table 2.** Regression model for average mean concentration of cabin climate as a function of number of passengers, location in aircraft, and flight level.

| *Parameter* | *Number of passengers* B (95% CI) | *Location in aircraft fwd/aft* B (95% CI) | *Flight level* B (95% CI) |
|---|---|---|---|
| Temperature (°C) | -0.02(-0.03-0.01) | -0.8(-0.9 –(-0.7))*** | -0.2(-0.06-0.02) |
| Air humidity (%) | 0.05(0.03-0.08)*** | 3.5(3.3-3.7)*** | -0.4(-0.5-(-0.3))*** |
| Carbon dioxide (ppm) | 4.1(2.9-5.2)*** | 37(28- 48)*** | -57(-61-(-53))*** |

*$P<0.05$; **$P<0.01$; ***$P<0.001$

Increase of temperature, air humidity, and carbon dioxide (B= regression coefficient) with confidence interval (95% CI), calculated by multiple linear regression.



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The influence of number of smokers and number of passengers on respirable particles concentration during cruise was investigated during smoke flights. In the crude analysis, there was a significant positive trend in the mean concentration of respirable particles in relation to number of smokers in AFT galley during cruise, with a mean value of 21 $\mu g/m^3$ at flight with few smokers, 27 $\mu g/m^3$ with normal number, and 66 $\mu g/m^3$ with many smokers onboard. The relationships were further investigated by a multiple linear regression model, keeping both number of passengers and number of smokers during smoke flights simultaneously in the model. In this model, flights with many smokers (>30 subjects) had 58 $\mu g/m^3$ higher concentration of respirable particles (95% CI 42-74 $\mu g/m^3$) in AFT galley, as compared to flights with few smokers (<20 subjects) ($p<0.001$). In contrast, there was no significant relationship between number of passengers and particle concentration.

Mean concentration of chemical contaminants in the cabin was low. The mean $NO_2$ and ozone concentration in AFT galley were 14.1 $\mu g/m^3$ and 13.7 $\mu g/m^3$, respectively. In the flight deck, mean $NO_2$ concentration was 7 $\mu g/m^3$ and ozone concentration was 26.3 $\mu g/m^3$. The highest ozone values were 76.1 $\mu g/m^3$ in the cockpit, 66.1 $\mu g/m^3$ in the AFT galley and 40.6 $\mu g/m^3$ in the forward galley. The highest values were measured during non-smoking flights. The concentration of formaldehyde was below the detection limit (<5 $\mu g/m^3$) during 17 out of 22 measurements. The maximum concentration (15 $\mu g/m^{3)}$ of formaldehyde was measured in AFT galley during a smoke flight with 190 passengers and a normal number of smokers (20-30 subjects).

Some of the MVOC were detected at relatively high concentrations. The levels of 3-methyl-1-buthanol and 2-methyl-1-butanol, 3 methyl-furan, and ethyl-butyrate was numerically higher than in Swedish dwellings. One preliminary sample from mineral fibre insulation indicated microbial growth, including *Pseudomonas* species.

## DISCUSSION

This study showed that when smoking is allowed, there is a considerable exposure to respirable particles in the rear part of the cabin. We could also demonstrate that there can be a pronounced difference in cabin air quality during cruise and non-cruise conditions. Finally, we found that relative air humidity during cruise can be extremely low at intercontinental flights, irrespectively of latitude.

We found that the cabin environment during non-cruise conditions was less favourable, with higher temperature, and $CO_2$-levels mostly exceeding recommended limit value (1,000 ppm). During cruise, cabin temperature varied between 17-25 °C. American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) has proposed a temperature standard of 19.5-23 °C winter and 22.8-26 °C summer for indoor environments in general (ASHRAE Standard 55-1992, 1992). The relative air humidity was very low (3-7 % R.H). ASHRAE recommends 30-60 % R.H. in indoor air (ASHRAE Standard 55-1992).

The average concentration of nitrogen dioxide and ozone in the cabin was low (14.1 and 19.2 $\mu g/m^3$, respectively). The measured ozone in our investigation was below the maximum permissible occupational limit values 100-200 $\mu g/m^3$ (The Occupational Safety and Health Administration in Sweden, 1996; ASHRAE, 1999; Joint Aviation Authorities/Joint Aviation Requirements, 2000; Federal Aviation Regulation 1998). More detailed measurements with a direct reading instrument are needed to evaluate possible peak exposure. Formaldehyde is an



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irritative compound commonly occurring in many indoor environments, such as dwellings (Garrett et al., (1999); WHO, 1989). Formaldehyde was below the detection limit (< 5 $\mu g/m^3$) in most measurements (77%), irrespectively of smoking. Volatile organic compounds of possible microbial origin (MVOC) were detected in the cabin air. The compound 3-methyl-furan is produced in the primary metabolism, and 1-octen-3-ol in the secondary metabolism, of many micro organisms.

## CONCLUSION AND IMPLICATIONS

In conclusion, cabin air quality and climate may differ between cruise and non-cruise conditions. On intercontinental flights, most of the time is spent during cruise, with very low relative air humidity in the working zones of both cabin attendants and flight deck crew. The large variation of cabin temperature shows a need for better temperature control. Finally, the study showed that tobacco smoking in commercial aircraft is a significant source of air pollution, with a pronounced increase of respirable particles in the rear part of the aircraft. Possible sources of detected VOC of possible microbial origin (MVOC) need to be further investigated.

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